DOCUMENT RESUME

ED 182 576 CE 024 261

AUTHOR Espy, John
TITLE Nuclear Technology. Course 28: Welding Inspection. Module 28-1, Welding Fundamentals and Processes.
INSTITUTION General Physics Corp., Columbia, Md.
SPONS AGENCY Office of Education (DHEW), Washington, D.C.
PUB DATE 79
CONTRACT 300-77-0340
NOTE 54p.; For related documents see CE 024 245-298

EDRS PRICE MF01/PC03 Plus Postage.
DESCRIPTORS Course Content; Energy; *Inspection; Learning Activities; Learning Modules; *Nuclear Physics; Postsecondary Education; *Quality Control; Teaching Guides; *Technical Education; *Welding
IDENTIFIERS Nuclear Energy; Nuclear Energy Occupations; *Nuclear Power Plant Technicians; *Nuclear Technology

ABSTRACT

This first in a series of ten modules for a course titled Welding Inspection describes the role and responsbilities of the quality assurance/quality control technician in welding inspections. The module follows a typical format that includes the following sections: (1) introduction, (2) module prerequisites, (3) objectives, (4) notes to instructor/student, (5) subject matter, (6) materials needed, (7) procedures, (8) data table, (9) reference materials, (10) test. (The course is one of fifteen technical courses for the second year of a two-year postsecondary curriculum in Nuclear Quality Assurance/Quality Control Technology.) (LRA)

**********
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
**********

ED182576

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

# NUCLEAR TECHNOLOGY

## COURSE 28 WELDING INSPECTION

### MODULE 28-1 Welding Fundamentals and Processes

CE 024 201

GENERAL PHYSICS CORPORATION
Columbia , Maryland

# COURSE MODULES

COURSE 28 WELDING INSPECTION


| | |
|---|---|
| Module 28-1 | Welding Fundamentals and Processes |
| Module 28-2 | Shielded Metal Arc and Oxyacetylene Welding |
| Module 28-3 | Tungsten Inert Gas (TIG), Metal Inert Gas (MIG) and Submerged Arc Welding |
| Module 28-4 | Weld Joint Verification |
| Module 28-5 | Qualifications |
| Module 28-6 | Process Controls |
| Module 28-7 | Acceptance Inspection |
| Module 28-8 | Filler Metal Control |
| Module 28-9 | Weld Repair Control |
| Module 28-10 | Records |



The material in this module was developed by General Physics Corporation under a contract with the United States Department of Health, Education and Welfare, Office of Education, Contract Number 300770340. Contractors undertaking such projects are encouraged to express freely their professional judgment in the conduct of the project. Therefore, points of view or opinions stated do not necessarily represent official Office of Education position or policy.

This module was prepared for General Physics Corporation by John Espy of General Physics.



GENERAL PHYSICS CORPORATION

1979

# INTRODUCTION

Metallic parts can be joined by mechanical connections, such as bolting, threading, and clamping, or by welding. Mechanical connections permit relatively easy disconnection for inspection, repair, or replacement but are not always suitable for the service or environment of the parts. Mechanical connections of parts containing pressurized fluid tend to leak. Space restrictions can greatly complicate the design of mechanical connections. High joint strength with high joint flexibility is difficult to obtain with mechanical connections. For these reasons and others, many metallic parts are joined by welding to obtain high strength, flexible, leak-tight and compact connections.

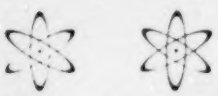
Welding of parts encompasses both joining of components and individual pieces of components. Chances are that the chairs, desks, and tables you are using contain pieces joined by welding. A glance at such welds quickly shows that shape and contour of weldments can blend with the desired shape and contour of the furniture. The history of welding shows advances aimed at speed, repeatability, and freedom from defects. A number of different welding processes have been developed which make it possible to choose the best welding process for any of a broad spectrum of applications. Each welding process has its unique advantages and techniques; the welding engineer reviews the techniques and advantages in order to select the welding process that is best for a specific application. The nuclear QA/AC technician, while normally not expert enough to be a qualified welder, needs to understand the fundamental characteristics of welding, the unique features of specific welding processes, and the effects on weld quality caused by the departure from qualified welding procedures. This understanding is necessary to permit

correct inspection of welding operations and proper application of inspection results.

This module describes the role and responsibilities of the QA/QC technician in welding inspections. It also discusses fundamental aspects of welding in order to provide the student/trainee with an adequate base level of knowledge. Knowledge of these fundamental aspects will equip the student/trainee to understand succeeding modules in this course and will familiarize him or her with many of the concepts and terms that are used in making a welding inspection.

The concepts and terms explained in this module are used in later modules of this course without additional description. Thus, it is important for the student to study the concepts and terms carefully and to be sure that he or she understands how they are used before going on to the next module.

This module first describes general responsibilities of the QA/QC technician in welding inspection, fundamentals of welding, welding techniques, common types of defects and heat treatment. It then presents a general overview of the five welding processes most frequently used in nuclear power plant welding.



## MODULE PREREQUISITES

None.

# OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Describe the general responsibilities of the QA/QC technician in welding inspection.
2. List five basic types of weld joints.
3. List one or more factors that affect the choice of joint type.
4. Describe the following weld joint features, using standard terminology, base metal, unaffected base metal, root gap, weld-end face, included angle, reinforcement, toe, weld metal, fusion zone, heat affected zone.
5. Discuss the electric arc heat source and the fuel flame heat source as they relate to the welding operation.
6. List two or more causes of distortion of the weld joint and describe four basic measures that control distortion.
7. State the purpose of filler material in a weld and list four basic types of filler material.
8. State the purpose of shielding during the welding operation.
9. List and describe seven welding techniques that are common to all welding processes.
10. List defects that are common to all welding processes. Describe the appearance of each type of defect and discuss its probable cause.
11. Discuss the effects of preheating the base metals, controlling interpass temperature, and post weld heat treatment on the weld.
12. Given each of the five welding processes most frequently used in nuclear power plants - oxyacetylene welding, tungsten inert gas welding,

shielded metal arc welding, metal inert gas welding, and submerged arc welding - describe the following aspects:

- apparatus need
- applications
- method of shielding
- type of heat source
- type of filler material

13. Given a weld specimen, identify the welding technique used, locate defects through visual examination, state probable causes of any defects found.
14. Identify by observation, the following aspects: the welding operation, the welding process, the welding technique, the type of shielding, the type of filler material, heat source, apparatus, and visible defects in the finished weld.

# SUBJECT MATTER

## GENERAL RESPONSIBILITIES OF THE QA/QC TECHNICIAN IN WELDING INSPECTION

Written procedures govern most aspects of the welding operation. These procedures specify such things as welder qualification, welding equipment and set-up, the welding process, heat treatment, and the types and sizes of unacceptable defects. In some instances, the written procedures also specify the welding technique. The purpose of these procedures are to prevent weld failure and to assure a good quality weld. The QA/QC technician must see that the written procedures for welding operations are applied and that the finished weld meets stated acceptance criteria.

Specific duties of a QA/QC technician vary, depending on the type of facility and on the requirements of the employer. In general, however, the QA/QC technician's duties in welding fall into three categories; verification, monitoring, and inspection. The QA/QC technician verifies that the welder is qualified and the welder has followed the written procedure for the set-up of equipment and for the use of parts. The QA/QC technician monitors the welding process while it is in progress to ensure that equipment and parts are used as the procedure specifies. After the welding operation has been completed, the QA/QC technician visually inspects the finished welds for unacceptable defects and for the specified amount of filler metal buildup. If work specifications require it, the QA/QC inspector also conducts and/or monitors non-destructive tests to detect defects. If unacceptable defects are found, the QA/QC technician may be responsible for monitoring the repair operation to ensure that repair procedures are followed and for reinspecting the repaired

weld. Finally, the QA/QC technician completes written reports on the disposition of the weld.

Welding operations and associated inspections are closely intertwined, such that the efforts of three disciplines (welding engineering, welders, and QA/QC) play vital roles in assuring that sound welds are made. This course is primarily geared toward the role of the QA/QC technician but includes ample information on the roles of welding engineering and welders to permit an understanding of the bases for the QA/QC role and its relationship to the other disciplines.

## FUNDAMENTALS OF WELDING

Welding is a process of joining metals by momentarily melting the adjoining surfaces of metallic parts, permitting the molten metal to coalesce, and then resolidifying the metals to form a bond between metallic parts. Anytime welding is done, written procedures govern the welding operation. A welding engineer writes procedures that specify the welding process to be used and as necessary describe specific welding techniques. These procedures must be consistent with and take into account, all applicable codes and regulations. The quality assurance engineer reviews all of the welding procedures and directs the quality assurance/quality control (QA/QC) technician to monitor the welding operation for compliance with these welding procedures. In order to assure compliance with welding procedures, the QA/QC technician must have a good grasp of the fundamentals of welding.

There are six fundamentals involved in obtaining a successful weld: the weld joint, heat source, distortion control, filler material, shielding, and appropriate

welding techniques. This module discusses each fundamental as it applies to any welding process.

## WELD JOINTS

### Configuration

The configuration of a weld joint directly influences the ultimate strength of the joint, the ease of welding and the probability of defect-free weldments. There are five basic types of joints: butt, corner, tee, lap and edge. Weld joints may also be squared or grooved. Figure 28-1-1 Fundamental Weld Joints illustrates these types.

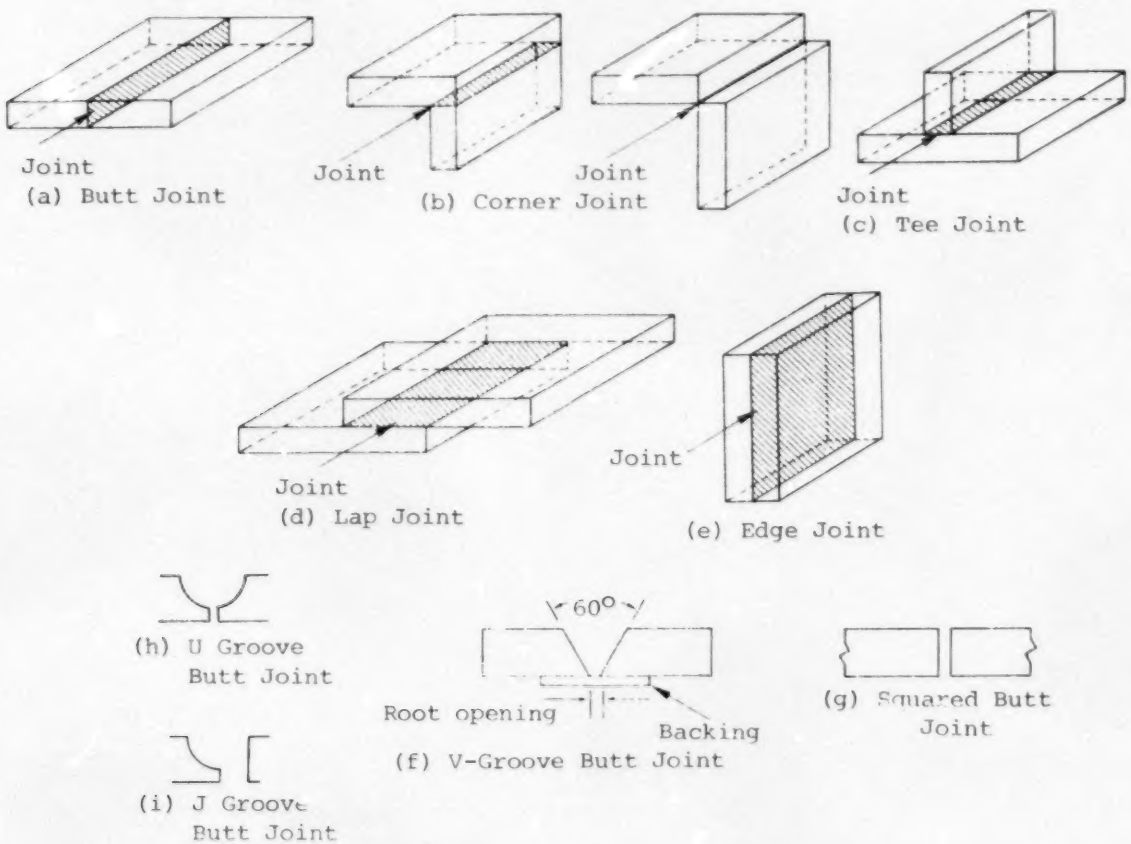



Figure 28-1-1 Fundamental Weld Joints

Considerations in Choosing Joint Type

The designer, normally in concert with the welding engineer, selects the basic type of joint to be used. Governing factors include space restrictions, shape envelope, strength requirements, and the stresses to which the joint will be subjected in service. In general, the butt joint is used where highest stresses will be applied. This joint provides uniform contour and, thereby, equalizes the stresses throughout the joint. The corner and tee joint cannot withstand as much stress as the butt joint but they are still high-strength joints. These two joints facilitate changes in space envelope where stresses do not dictate that a butt joint be used. The lap joint is used in low stress applications or where there is moderate stress only in the direction parallel to the surfaces of the overlapping plates. The edge joint is used in low stress applications. Most nuclear welding employs butt, corner, and tee joints. Lap joints, and less frequently edge joints, are sometimes used in building construction.

Another important factor with respect to the strength of a weld joint is the extent of fusion of welding. If the entire area and volume of the weld joint is fused by welding, the weldment is a full penetration weld. Conversely, fusion of only a portion of the area and volume of the joint gives a partial penetration weld. Obviously, a full penetration weld has the higher strength. To facilitate full penetration, joints are grooved as shown in Figure 28-1-1. The groove permits access by the welding heat source to the root opening. Given such access, the complete joint is fused by a series of passes by the welding heat source. The squared joint shown in Figure 28-1-1 doesn't provide direct access to the root opening.

It would not permit full penetration welds except for thin materials where the entire joint can be fused in one pass of the welding heat source. The U and J joints as shown in Figure 28-1-1 permit as good penetration as the V joint, but with less weld metal and time, especially in thick material.

Terms Used to Describe Joint Features

Standard terminology is used in describing weld joint features. Most frequently used terms are defined as follows and illustrated in Figure 28-1-2.

- Base Metal - the metals to be joined by welding
- Unaffected Base Metal - the base metal whose chemistry and physical properties are unaffected by the welding process
- Root Gap - the distance between the surfaces to be welded measured at the bottom of the weld joint
- Weld End Face - the surface area of the surfaces to be joined by welding
- Included Angle - the angle formed by the perpendicular centerline of the weld joint and the weld end face
- Reinforcement - weld metal thickness in excess of nominal base material thickness specified for the weld joint
- Toe - the interface of either side of the weld metal with the base metal along the longitudinal surfaces of the weld joint
- Weld Metal - the volume of metal whose chemistry and physical properties are those of the mixture of added filler material and base metal

Figure 28-1-2 illustrates the joint features described in this module.

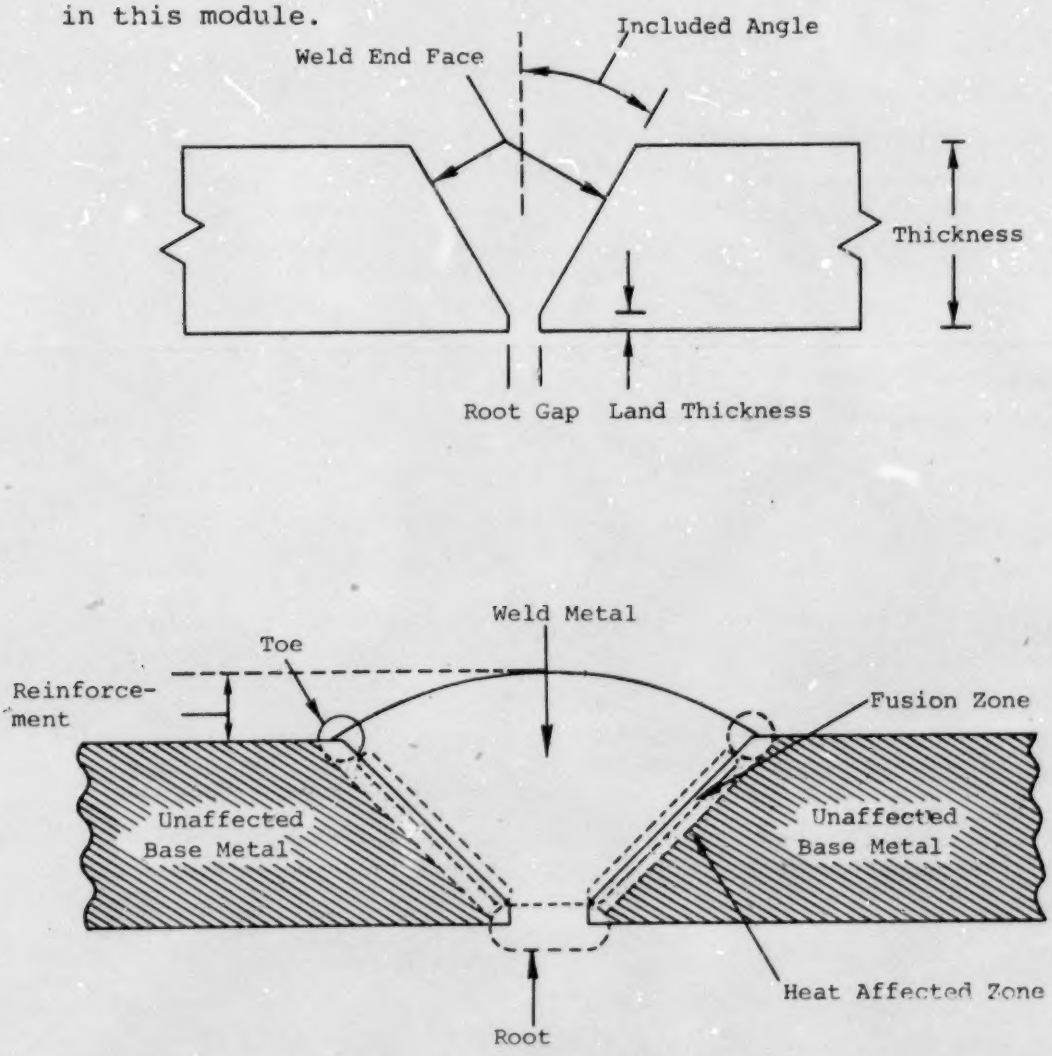



Figure 28-1-2 Weld Joint Features

- Fusion Zone - the volume of base metal and filler material in the vicinity of the weld end faces which melts and resolidifies during the weld process
- Heat Affected Zone - the volume of base metal which did not melt, but whose physical properties were altered by the heat of welding
- Root - the volume of base metal and filler material melted and resolidified by the first welding pass.

## HEAT SOURCES

### General

As heat is applied, it is conducted throughout the metals to be joined. Since the parts are metallic, rapid loss of heat occurs, particularly when massive parts are to be welded. The heat source, therefore, must input heat very rapidly to melt only the weld end faces without bringing the entire mass to the melting point of the base materials. The QA/QC technician verifies that the heat source specified in the welding procedures is used. Fuel flame and electric arc are the two basic types of heat sources used for fusion welding.

### Fuel Flame Heat Source

Fuel flame heat source consists of oxygen and a combustible fuel. Due to its high heat generation, acetylene is frequently used as the fuel. The oxyacetylene flame consists of oxygen and acetylene and is applied directly to the weld end faces until melting occurs. Controlling movement of the flame along the weld joint permits melting

new areas and resolidification of previously melted areas. This type of fuel flame heat is shown in Figure 28-1-3.

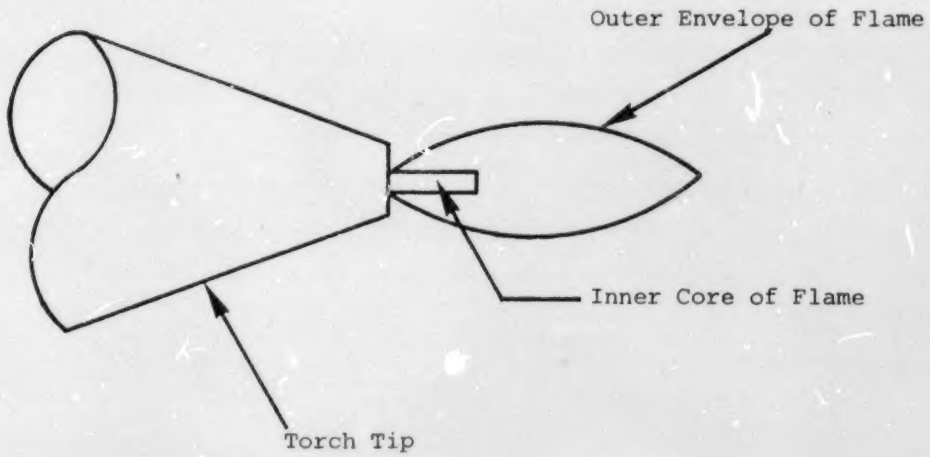



Figure 28-1-3 Fuel Flame Heat Source

Electric Arc Heat Source

Electric arc heat source uses the power generated by electrical current flow through a resistance. This power in watts can be calculated by formula 28-1-1 which is derived as follows:

$E = IR$, then, (Ohm's law) Formula 28-1-1

$W = EI$, then, (based on Ohm's law)

$W = IRI = I^2R$ (substituting IR for E)

Where: E = Voltage

I = Current

R = Resistance

W = Watts

Notice that the power in watts increases rapidly as the current is increased. This happens because power is proportional to the square of current. Since this power in an electric arc exists as light and primarily heat, large heat inputs can be derived from moderate current values, e.g., 20 to 500 amperes of current. (Amperes is a measure of current flow where one ampere is equal to one coulomb of charge moving past a given point in one second. One coulomb is the charge represented by $6.3 \times 10^{18}$ electrons.)

In an electric arc heat source, the arc path presents a high resistance to current flow, as compared to the resistance of base metals. Therefore, practically all of the heat generated by the current flow is dissipated in the arc. The fundamental features of an electric arc are shown in Figure 28-1-4 below.

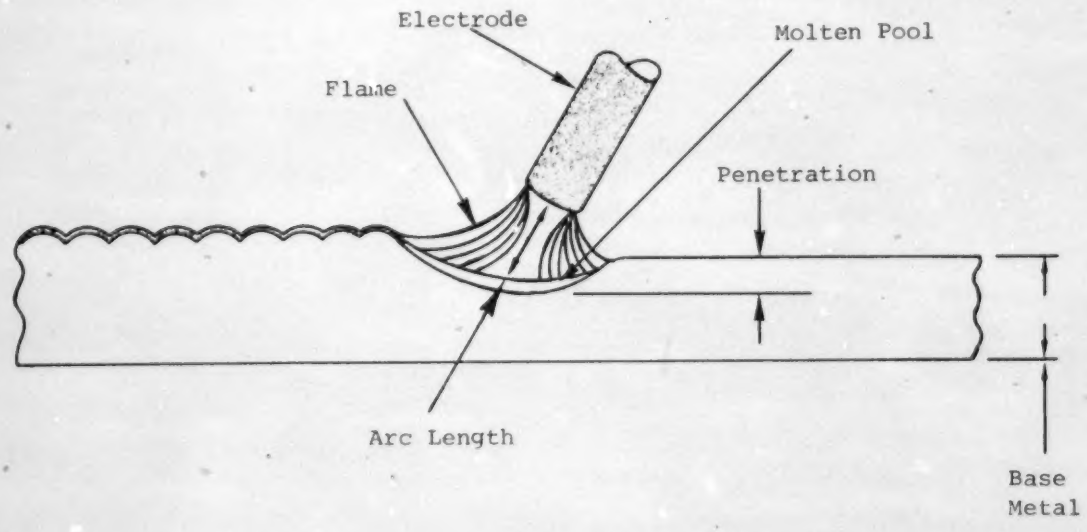



Figure 28-1-4 Electric Arc Heat Source

# DISTORTION CONTROL

## General

Distortion of the weld joint can lead to weld failure. Therefore, the weld engineer in his or her design of welding processes, is careful to specify or describe fixturing that minimizes distortion. The QA/QC technician inspects the placement of fixturing to determine whether specified distortion control measures have been applied. To carry out this task, the QA/QC technician must recognize possible causes of distortion and must be familiar with distortion control.

## Causes of Distortion

The atoms of metals arrange themselves in definite patterns (crystals) as metals solidify during welding. The size of these crystals varies considerably, depending on such factors as type of metal and the cooling rate through the temperature at which solidification occurs. The welding process can result in crystals of different sizes from those originally in the base metal and, therefore, cause distortion of the weld joint. Another cause of distortion of the weld joint is the temperature difference (gradient) from the weld end faces to the surrounding base metal. This temperature gradient causes internal stresses which distort the weld joint. Also the molten weld metal shrinks considerably in solidification and cooling, possibly resulting in residual stress and distortion.

Distortion Control Measures

Distortion of the weld joint is undesirable because it may lead to weld failure at some point in time due to non-uniform application of stresses. Also, distortion makes it difficult, if not impossible, to comply with dimensional requirements and, if the joint is in a flow path, it may restrict flow. Distortion can be minimized by the application of control measures in the welding process. Distortion can be controlled and minimized by the following measures:

- Selection of the correct base metal - Certain metallic alloys solidify with only one crystal size possible.
- Physical restraint - Clamps and fixtures are used to physically restrain the parts to be welded.
- Proper joint design - Proper joint design permits easier control of the heating and cooling rates during the welding process.
- Proper welding techniques - Heating rates are selected which result in proper welding (uniform fusion), while minimizing distortion due to internal thermal stresses. Further, distortion is minimized by preferential welding, i.e., alternately welding different areas of the weld joint to avoid excessive localized internal stresses.

## FILLER MATERIAL

### General

If the weld metal is formed solely by melting the weld end faces, insufficient material is available to "fill up" the joint, (See Figure 28-1-1). Unless extra metal is added, the resulting weld will be thinner than the base material thickness.

Extra metal (filler material) can be preplaced in the joint and melted by welding or it can be fed into the heat source such that it is added continuously to the localized area being melted. Other than consumable inserts, preplaced filler material is normally not used in the nuclear power applications because of the difficulty in assuring that all such metal has been melted and thereby fused uniformly. Further, preplaced filler material requires more heat input and thereby increases risk of distortion.

The filler material for a weld is specified in the welding procedures. Before a weld is made, the QA/QC technician inspects the filler material to be sure that it is the filler material that is specified in the welding procedures.

### Types of Filler Materials

There are four basic types of filler material used in nuclear power plant applications. They are: coated electrode, straight length bare rod, spooled bare rod, and consumable inserts. The straight length bare rod is normally used with the oxyacetylene flame welding process. Any of the four types of filler materials may be used in the electric arc welding process. Figure 28-1-5 illustrates the four basic types of filler materials.

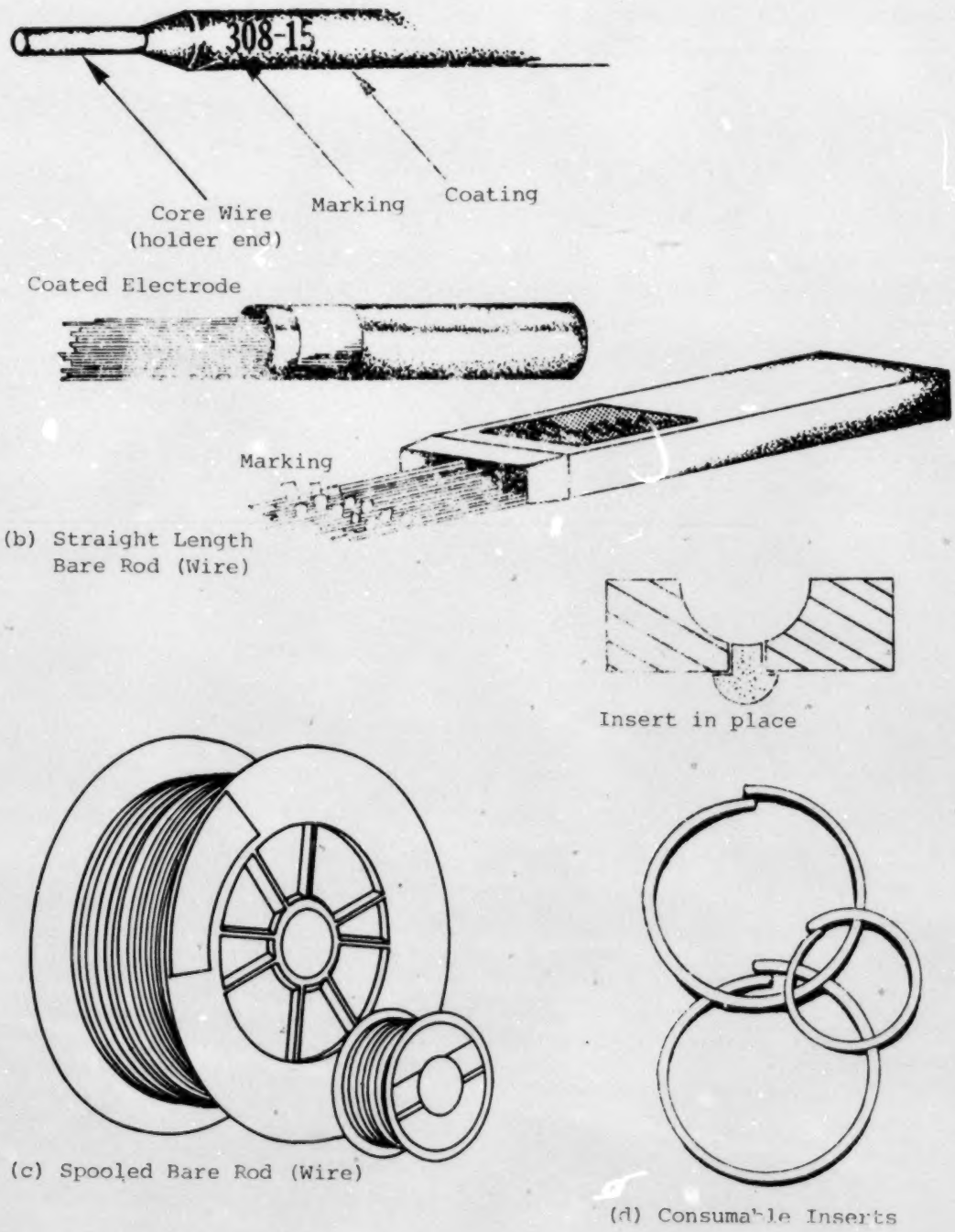



Figure 28-1-5 Types of Filler Materials

## SHIELDING

Each welding process requires some means of shielding the hot weld metal from the atmosphere in order to prevent corrosion during welding. The earth's atmosphere is composed of about 80% nitrogen and 20% oxygen. Most metals have a strong tendency to combine with oxygen and a lesser tendency to combine with nitrogen. This tendency grows as the temperature of the metals increases, such as during welding. The resulting oxides and nitrides are weak and brittle and represent serious problems to the soundness of a welded joint. The oxides and nitrides may become entrapped within the weld bead or may form surface films which preclude complete fusion as the next welding pass occurs. Nitrogen and hydrogen will also dissolve in certain metals (aluminum, low alloy steels and zirconium for examples) and thus introduce internal stresses which cause cracking. A simple means of removing oxygen, nitrogen and hydrogen from the vicinity of the weld joint is to displace these elements with a substance which is not harmful to the weld. The displacement substance is called shield or shielding and is discussed later in this module.

The welding procedure specifies shielding material. Right before and/or during a welding operation, the QA/QC technician inspects the shielding material to be sure that the specified material is used.

## WELDING TECHNIQUES

### General

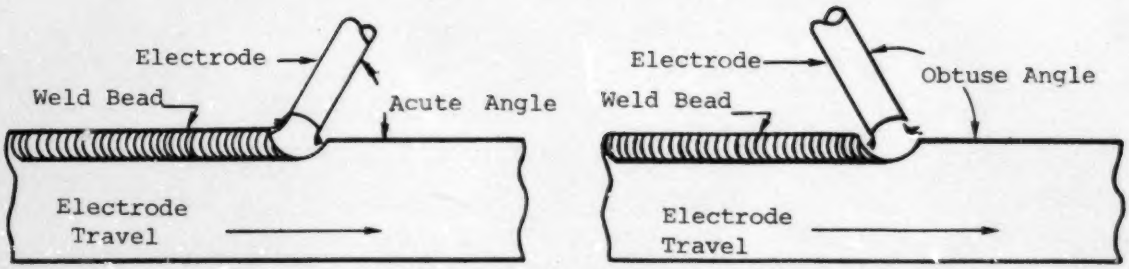
The same welding technique is not used for every welding process or for every weld joint. Rather, the

welding technique that will produce the best results, given a particular welding process or joint configuration, is selected. Usually, the welder selects the technique, but sometimes the welding technique is specified in the welding procedure. If the technique is specified in the welding procedure, the QA/QC technician monitors the welding process to ensure that the specified technique is used.

While each welding process involves some unique techniques, many techniques are common to all of the welding processes. Seven common techniques are examined in this module: forehand and backhand; single pass and multipass; weave and stringer bead; positional; interpass cleaning; reverse side welding techniques; and vertical progression.

Forehand and Backhand Techniques

The backhand and forehand techniques are used to shape the molten weld puddle to obtain uniform fusion with little irregularity in the thickness of the resultant weld bead. Shaping of the puddle is possible because the flame or electric arc exerts a force on the molten weld puddle which "pushes" the puddle in the direction of the force. The effect of this force is controlled by adjusting the angle of the flame or electrode in relation to the work piece. As shown in Figure 28-1-6, this angle may be acute (less than $90^{\circ}$) as in the backhand technique or obtuse (greater than $90^{\circ}$ and less than $180^{\circ}$) as in the forehand technique. The forehand technique gives easiest control of the puddle when using the oxyacetylene heat source. The backhand technique is normally best for the electrical arc welding process. It permits a smaller included angle (narrower) groove, saving filler, and usually yields a higher quality weld.




(a) Backhand Technique (b) Forehand Technique

Figure 28-1-6 Backhand and Forehand Welding Techniques

Single Pass and Multipass Technique

The single pass technique completes the weldment with one traversal (pass) of the heat source while the multipass technique uses two or more passes of the heat source. (The discussion on distortion control noted the importance of controlling the rate of heat input and resulting thermal gradient from the weld joint to surrounding base metal.) The amount of heat input required is directly proportional to the volume of metal to be melted with a single pass of the heat source.

If the entire weld joint is to be welded in one pass of the heat source, a large heating rate is necessary, particularly as the thickness of the joint increases. Therefore, a single pass technique can be used for relatively thin weld joints but is unsuitable for thicker joints. The multipass technique permits low rates of heating because less volume of metal is melted per pass.

Weaver and Stringer Bead Techniques

Welding naturally progresses along the length of the weld joint (longitudinal axis of the joint). However, the heat source may also be moved tranversely at the same time it is moved in the longitudinal direction. The weave bead technique employs both movements such that the complete width of the joint is welded as the length is welded. The weave bead technique requires fewer steps for bead cleaning because there are fewer weld beads. Also, it requires fewer total passes of the heat source to complete a multi-pass weld. It is very good for vertical, single pass welds. A disadvantage of the weave bead technique is the higher probability of incomplete fusion because the molten weld puddle is being pushed in several directions and the fusion zone alternately changes from weld end face to weld bead.

The stringer bead technique uses little or no weaving in the traverse direction. Since the molten weld metal is being pushed in essentially one direction, uniform fusion is more easily assured. More cleaning steps are needed, however, because more beads are needed to complete the weld. These techniques are shown in Figure 28-1-7.

Positional Techniques

The welder may be able to position parts to be welded or the parts may be immobile. Since various physical positions of the weld joint give different degrees of difficulty in making a sound weld, the welding procedure and the welder's techniques must be tailored for the position to be used. Because gravity is always attracting the molten weld puddle, the most favorable positions are those which physically limit the flow of molten metal. There are four basic welding positions: flat, horizontal, overhead, and vertical. Each position is shown in Figure 28-1-8, which

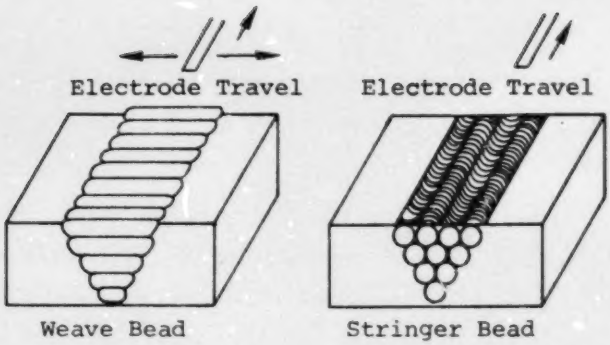



Figure 28-1-7 Bead Techniques

is taken from Section IX ASME Boiler and Pressure Vessel Code.

- Flat Position presents least difficulty for controlling the molten weld puddle. The force of the fuel flame or electric arc controls the shape and flow of the molten weld puddle relatively easily and thus offers high assurance of uniform fusion. Oftentimes, components are rotated by positioners to maintain the flat position at the point of welding. Welds are in the flat position if their longitudinal axis is from $0^{o}$ to $15^{o}$ from the horizontal plane while their perpendicular axis is within $30^{o}$ either side of vertical.
- In the Horizontal Position, it is more difficult to control the molten weld puddle because the weld joint geometry permits flow of the puddle due to gravitational forces. A little more precision in controlling the angle of the heat source is needed to counter the gravitational force and thus assure uniform fusion. Welds are in the horizontal position when their

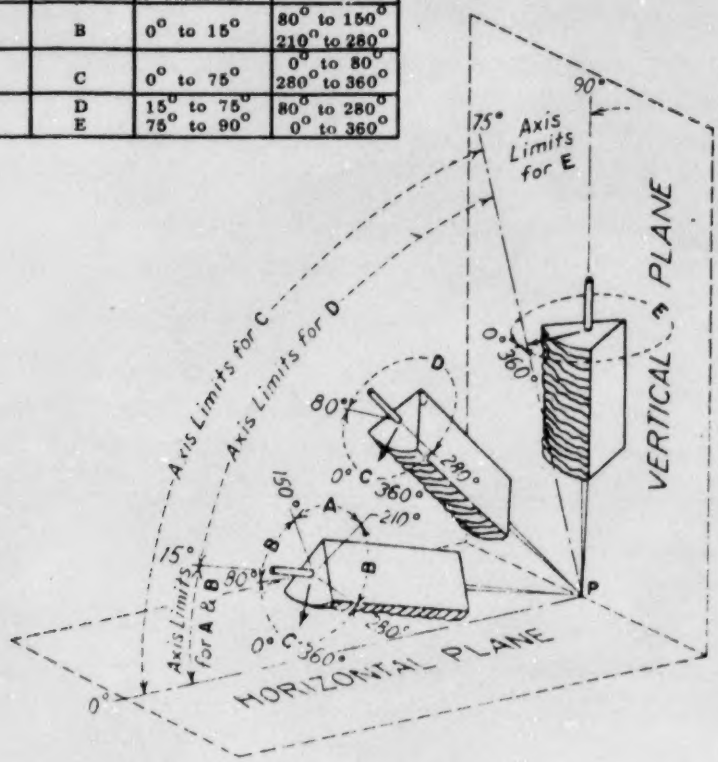
longitudinal axis is $0^{o}$ to $15^{o}$ from the horizontal plane while their perpendicular axis is between $30^{o}$ and $100^{o}$ either side of vertical.

- Overhead Position and Vertical Position have the highest degree of difficulty for making a sound weld. In the overhead position, the molten weld puddle is likely to drip from the weld joint. Molten weld metal in the vertical position is likely to run down the weld end faces. In addition to controlling the angle of the heat source, it is usually necessary to lower the heating rate which reduces the mass (weight) of metal that is molten at any given time. Therefore, the overhead and vertical positions are not only difficult to weld properly but also more time consuming because each welding pass fuses less volume of metal than can be fused in the flat or horizontal positions. Welds are in the overhead position when their longitudinal axis is $0^{o}$ to $75^{o}$ from the horizontal plane while their perpendicular axis is between $100^{o}$ and $260^{o}$ from vertical. Welds are vertical under two conditions: (1) Longitudinal axis is $15^{o}$ to $75^{o}$ from the horizontal plane while perpendicular axis is within $100^{o}$ either side of vertical, or (2) Longitudinal axis is $75^{o}$ to $90^{o}$ from the horizontal plane regardless of the position of the perpendicular axis.

Vertical Progression Technique

Welding progression (i.e., direction of travel of heat source along the longitudinal weld axis) has about the same degree of difficulty for controlling the molten weld puddle

| TABULATION OF POSITIONS OF WELDS | | | |
|---|---|---|---|
| Position | Diagram Reference | Inclination of Axis | Rotation of Face |
| Flat | A | $0^{\circ}$ to $15^{\circ}$ | $150^{\circ}$ to $210^{\circ}$ |
| Horizontal | B | $0^{\circ}$ to $15^{\circ}$ | $80^{\circ}$ to $150^{\circ}$<br>$210^{\circ}$ to $280^{\circ}$ |
| Overhead | C | $0^{\circ}$ to $75^{\circ}$ | $0^{\circ}$ to $80^{\circ}$<br>$280^{\circ}$ to $360^{\circ}$ |
| Vertical | D<br>E | $15^{\circ}$ to $75^{\circ}$<br>$75^{\circ}$ to $90^{\circ}$ | $80^{\circ}$ to $280^{\circ}$<br>$0^{\circ}$ to $360^{\circ}$ |




NOTE: The horizontal reference plane is taken to lie always below the weld under consideration.

Inclination of axis is measured from the horizontal reference plane toward the vertical.

Angle of rotation of face is measured from a line perpendicular to the axis of the weld and lying in a vertical plane containing this axis. The reference position (0 deg.) of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. The angle of rotation of the face of weld is measured in a clockwise direction from this reference position (0 deg.) when looking at point P.

Figure 28-1-8 Welding Positions

in the flat, horizontal, and overhead positions. However, for the vertical position, different angles of the heat source are needed between progressing up the joint and progressing down the joint. For this reason, vertical progression (up or down) is often considered an essential variable which requires specific tests to assure that the progression to be used will result in a sound weld.

Interpass Cleaning Technique

After each pass of the heat source in most welding processes, the weld bead needs to be cleaned in order to prevent entrapping foreign materials by the next pass. Cleaning methods include: chipping with a slag pick, wire brushing (manual and powered), and grinding. Since different degrees of cleanliness are obtained with these cleaning methods, the method used during qualification of the welding procedure must be used during production welding.

Reverse Side Welding Technique

It is typically more difficult to obtain a quality weld in the root than in the remainder of the weld joint. If the weld joint is welded only from one side, more stringent controls are needed for such factors as root gap dimensions, backing, and heating rate for the root pass in order to avoid defects in the root. Even with stringent controls, subsequent inspection may find defects in the root and the entire weld, for the weld volume where the defects are located, must be removed down to the root and then rewelded. This problem can be avoided if space is available to weld both sides of the weld joint. After welding one side, the backside of the deposited weld metal is gouged out, which removes the original root area and any defects which may have existed.

Back gouging may be accomplished by chipping or grinding, or arc gouging, and it is performed in a manner which forms the dimensions of the backside that are suitable for welding. Since substantially different techniques are employed for welding one side, as opposed to welding both sides, production welding must use the technique that has been tested and proven satisfactory on a weld mockup.

## WELD DEFECTS

### Types of Defects

Defects may occur in the welded joint when there is inadequate control of any of the six fundamentals discussed in this module. Certain defects are acceptable, depending on the size of the defect and the intended use of the welded joint. The designer of the weld joint stipulates the types of defects and the size of defects that are unacceptable. The QA/QC technician inspects the completed weld to determine whether any defects present are acceptable or unacceptable.

Each welding process has characteristic defects associated with it. However, there are many defects that are common to all welding processes. This module describes the defects that are common to all welding processes. They are: incomplete fusion; cracking; inclusions; porosity; undercutting; root concavity; root convexity; burn through or melt through; and underbead cracking.

### Incomplete Fusion

Incomplete fusion is the failure to melt together the filler metal and base metal or the failure to melt one filler metal bead to another filler metal bead. Incomplete

fusion is most likely to occur along the weld end faces and between beads of multipass welding. Incomplete fusion is caused by insufficient heating rate, excessive weaving, improper control of angle of heat source or insufficient accessibility by the heat source for complete melting.

Cracking

Cracking is separation in the normal bond among the atoms of the crystalline structure. Cracks may appear anywhere in the weld joint where melting and resolidification have occurred. They are caused by excessive heating or cooling rates and, when more than one type of metal is used in the weld joint, by differences in expansion coefficients between the metals used. It may also be caused by hydrogen embrittlement due to improper welding, heat treatment or plating technique; or improper control of delta ferrite in stainless steel. Delta ferrite is a form of iron which is included in stainless steel alloy welding filler metals for the purpose of increasing the resistance of the deposited metal to cracking.

Inclusion

Inclusion is entrapment of foreign material in the weld metal. Inclusions may occur throughout the weld joint and are caused by inadequate interpass cleaning, excessively rapid solidification of the molten weld puddle (caused by combination of low heating rate and fast travel speed of heating source), or inability of the heat source to "float out" inaccessible foreign material. Oxide inclusions can occur when shielding is lost.

Porosity

Porosity refers to cavities in the weld metal. Porosity is caused by entrapment of gases in the weld metal as

solidification occurs. Porosity can occur in any portion of the weld metal. It is caused by excessively rapid cooling and solidification of the molten weld puddle.

Undercutting

Undercutting is an intermittent or continuous depression or groove along the toe or root of the weld left unfilled by weld metal. Undercut is caused by excessive heating rates, insufficient addition of filler metal, or by insufficient number of weld passes.

Root Concavity

Root concavity is a depression in the root surface of the welded joint. It may be caused by gravity or improper combination of heating rate and travel speed of the heat source.

Root Convexity

Root convexity is excessive reinforcement at the root of the weld joint. It may be caused by gravity or by the improper combination of heating rate and travel speed of the heat source.

Burn Through or Melt Through

Burn through or melt through is a convex or concave irregularity on the root surface or adjacent base metal. The irregularities may be voids caused by the falling away of weld metal or may be attached, solidified droplets. Excessive heating rate or insufficient travel speed of the heat source causes burn through. Also inadequate backing may permit burn through.

Underbead Cracking

Underbead cracking is a cracking in the heat affected zone. Such cracks may or may not extend to the surface of the weld joint. Underbead cracking is caused by hydrogen and excessive heating and cooling rates of the heat affected zone.

Location of Defects

Figure 28-1-9 shows the location in the weld of common weld defects.

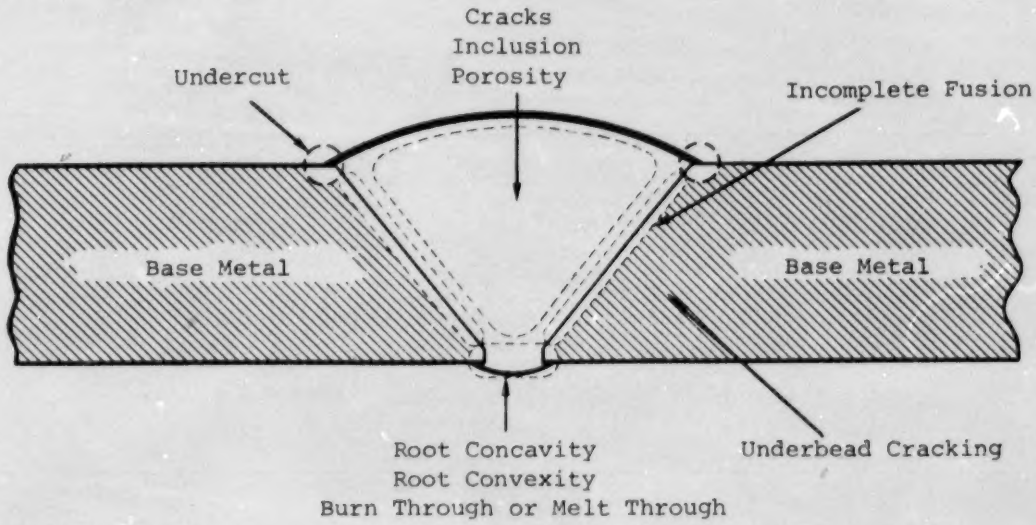



Figure 28-1-9 Location of Welding Defects

HEAT TREATMENT

Purpose

Carbon and low alloy steels have a tendency to crack when cooling rates are high. Other alloy steels, such as

austenitic stainless steel, can have undesirable carbon migrations toward grain boundaries when they are welded. Further, hardenable alloys are hardened only in localized spots when welded. For these reasons, as well as other reasons, the welding engineer has to determine for each alloy that is to be welded, the effect that welding will have on the mechanical properties of the weldment. Whenever the welding engineer determines that some adverse effect due to welding is likely, he or she specifies a heat treatment countermeasure in the welding procedures. The QA/QC technician monitors the heat treatment to be sure that the specified counter measure is applied. The QA/QC technician also inspects the weldment after the heat treatment has been applied.

Heat treatment countermeasures commonly specified in the welding procedure include: preheating base metals prior to welding; controlling interpass temperature; and conducting past weld heat treatment.

Preheating

Preheating is the application of heat to the base metal prior to welding to bring the temperature of the base metal to the specified preheat temperature. Natural gas torches and electric induction heaters are two common heat sources for preheating.

Preheating retards the cooling rate in the weld metal and heat affected zone. It also lowers the magnitude of thermal stresses by reducing the temperature gradient from the weld metal to the surrounding base metal. The lower cooling rate permits recrystallization of weld metal with the desirable grain structure which does not have the tendency to crack. Hence, weld metal cracks and underbead cracks are avoided.

Interpass Temperature

Interpass temperature is the temperature of the weld metal before the next welding pass is started. It is measured immediately prior to starting the next pass. Interpass temperature is governed by the time interval between passes, i.e., how much cooling occurs prior to welding heat being reapplied.

Some steel alloys will form low strength crystals when cooling is particularly slow. In such cases, a maximum interpass temperature is specified and the welder must wait a sufficient time before welding the next pass to permit the interpass temperature to cool below the maximum.

Post Weld Heat Treatment

Post weld heat treatment is the application of heat to a weldment after welding is completed. If the weldment is portable, post weld heat treatment is normally accomplished in a furnace or oven. If the weldment is not portable, gas torches or electric induction heaters are used.

The nature of the post weld heat treatment is dependent on the properties of the particular alloy that has been welded. Some alloys do not require post weld heat treatment. In general, alloys that require preheating also require post weld heat treatment.

Stress relieving post weld heat treatment as the name implies, reduces the residual stresses from welding. In general, stress relieving is accomplished by heating the weldment to 1100 to 1200$^{o}$F, holding this temperature for one hour per inch of weld joint thickness, and slowly cooling from this temperature. The necessity for stress relieving increases with higher carbon content, increased

alloy content, and larger cross-sectional areas of weldments. It is noted that mechanical stress relief by vibration is also finding increasingly wider use.

Stabilization heat treatment and solution anneal heat treatments are means of redissolving carbon into grain crystals. Such heat treatments are made necessary for alloys where welding drives carbon from solution into grain boundaries thereby weakening the corrosion resistance of the alloy and affecting its ductility.

## WELDING PROCESSES

### Five Types

Five welding processes are frequently used in nuclear power plant welding. They are: oxyacetylene welding, tungsten inert gas welding, shielded metal arc welding, metal inert gas welding, and submerged arc welding. This module briefly discusses the qualification of welding processes and the QA/QC technicians responsibilities during welding processes. It then describes each welding process and its uses. Later modules of this course present more detailed information on each welding process.

### Qualification of Welding Processes

Each welding process affects the chemical and mechanical properties of the weld. Before any welding process can be used, its effects must be identified, examined and found acceptable through rigorous testing. The chemical and mechanical properties that result from a given welding process cannot be studied by nondestructive examinations of a weld. Rather these properties are studied by conducting various destructive tests on a test piece or test specimen of welded metal. The study of the weld's pro-

perties is often called "qualifying" the welding process. A welding process is said to be "qualified" if destructive and nondestructive testing of a test specimen reveal that the mechanical and chemical properties of the test specimen meet requirements set by the governing welding code or standard. For example, ASME Boiler and Pressure Vessel Code gives welding procedure qualification requirements in Section IX of the code.

A welding process is not requalified every time that it is used. It is known that, if a qualified welding process is applied without substantial change, the chemical and mechanical properties of the weld are essentially the same as the properties of the test piece.

The welding procedure specifies the welding process or processes that can be used for a given welding operation. The QA/QC technician monitors the welding process to assure that it complies with the specific welding procedure and that it is carried out within the limits of the qualification granted to the procedure. In order to perform this monitoring responsibility, the QA/QC technician needs to understand various welding processes and their accepted uses.

Oxyacetylene Welding

The oxyacetylene welding process is a fuel flame welding process that employs portable equipment that does not require external power sources. Oxygen and acetylene are fed from pressurized bottles to a mixing torch where the gases are mixed and ignited at the torch tip. The inner core of the flame (See Figure 28-1-3) is manipulated by the welder to control molten weld puddle size and flow. Shielding is provided by the outer envelope of the flame. Straight length bare rod (See Figure 28-1-5) is fed into the intersection of the core and the work piece where it

melts and coalesces with the base metal molten puddle. Heating rate is dependent on size of torch and amount of time the flame is held in one location. The size of the molten weld puddle depends on the heating rate and the rate of adding filler material. This welding process is schematically represented in Figure 28-1-10.

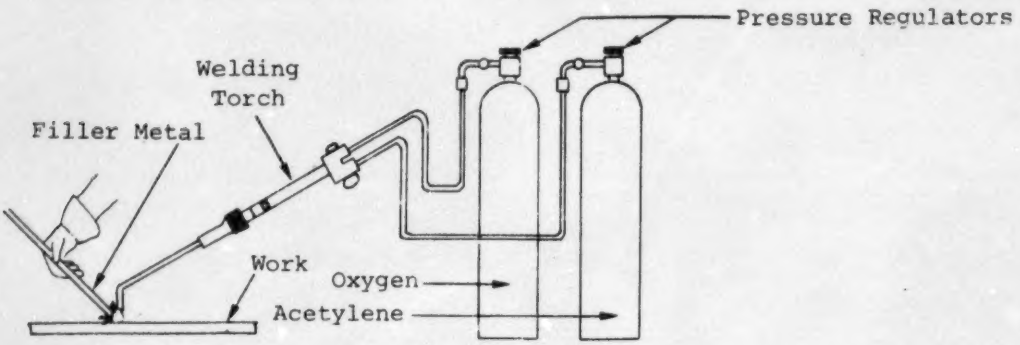



Figure 28-1-10 Schematic Diagram of the Oxyacetylene Welding Process

Uses of the Oxyacetylene Welding Process

Oxyacetylene welding is suitable for all types of base metals and joint designs, however, it is not frequently used for joint welding of steel because it is a relatively slow welding process and is not easily automated. It is used for joint welding of copper and aluminum base alloys, for hardsurfacing parts and occasionally for repair welding of small areas in any type of base metal. Hardsurfacing involves the use of a straight length bare rod that has high hardness, such as chrome, nickel-chrome, or cobalt-chrome. The surface of the deposited weld metal is comprised mostly of the filler material and therefore retains a very high hardness. The resulting surface gives good wear properties and is frequently

used for surfaces which rub other surfaces in service (valve seating surfaces, for example).

Tungsten Inert Gas Welding

In this electric arc welding process, both electrical power and a shielding gas are fed through an electrode holder to the work piece. The arc is maintained between a tungsten electrode, which does not melt, and the work piece. Shielding gas (e.g., argon, helium) from a pressurized bottle flows around the electrode and the arc. Filler material must be supplied separately by feeding into the arc either straight length or spooled bare wire (See Figure 28-1-5). Equipment for the tungsten inert gas welding process is schematically represented in Figure 28-1-11.

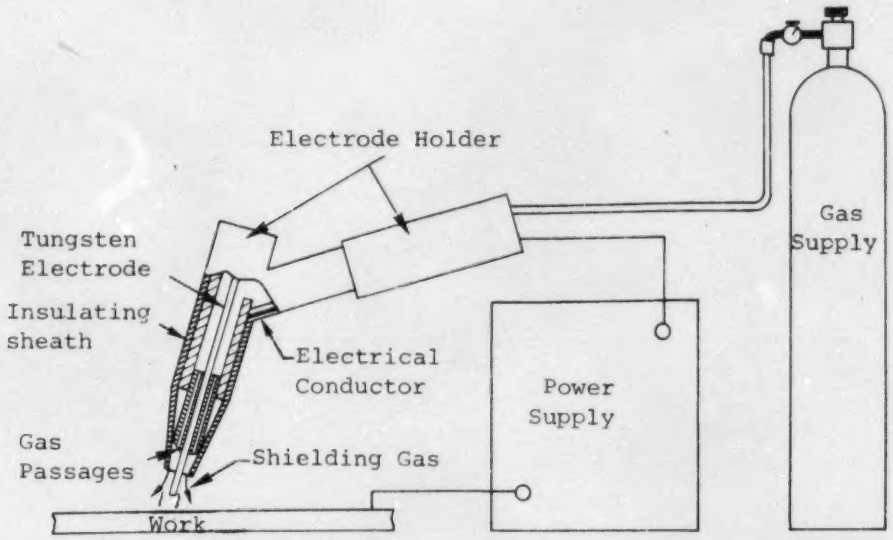



Figure 28-1-11 Schematic Diagram of the Tungsten Inert Gas Welding Process

Use of Tungsten Inert Gas Welding Process

Tungsten inert gas welding can be employed for all types of base metals and it is readily automated. Since no slag is present and precise heating rates are obtainable, it is often used for root pass welding. Its precise heating rates make it suitable for welding very thin parts and for welding in any position. The disadvantages of tungsten inert gas welding are: (1) It requires low to moderate welding speeds and (2) Any opening with a smaller diameter than the gas cup surrounding the tungsten electrode is inaccessible.

Shielded Metal Arc Welding

In shielded metal arc welding as in all electric arc welding, an external power source is needed. An electrical power supply provides voltage and current through electrical cables to an electrode holder and the work piece. The coated electrode (See Figure 28-1-5) completes the electrical circuit when it is struck against the work piece. The electrode's coating and core wire melt in the arc to provide shielding and filler material respectively. Heating rate is dependent on the voltage and current settings of the power supply. Arc length is manually controlled by the welder. Figure 28-1-12 depicts the shielded metal arc welding process.

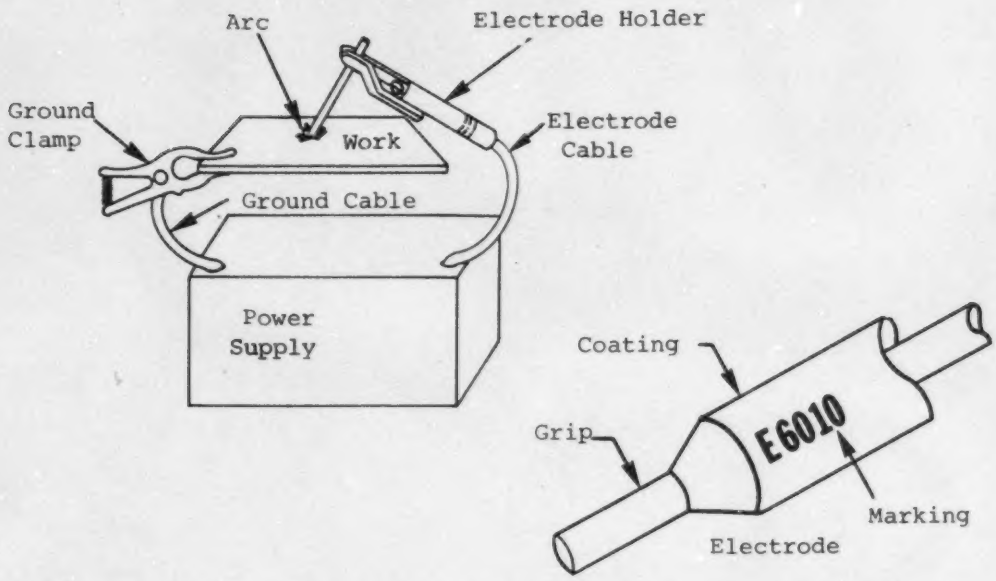



Figure 28-1-12 Schematic Diagram of the Shielded Metal Arc Welding Process

Uses of Shielded Metal Arc Welding Process

Shielded metal arc welding is widely used for welding of ferrous and nickel alloys. It offers good control of size and flow of the molten weld puddle and it can be used in any position. However, it cannot be easily automated and it is a poor choice for root passes due to the risk of burn through and slag inclusions. Further, it is not readily adaptable to copper and aluminum base alloys.

Metal Inert Gas Welding

Complex equipment is needed for the metal inert gas welding process. In addition to an electrical power supply and pressurized shielding gas, controls are needed to feed bare wire into the arc at a sufficient rate. Since the arc is maintained between the bare wire and the work piece and the bare wire is constantly melting, wire feed rate must be set to maintain proper arc length with a given combination of electrical power and travel speed. Argon, helium

or carbon dioxide may be used for shielding. Straight length of spooled bare wire may be used for filler material but spooled bare wire is mostly used to take advantage of the speed of this process. Heating rate is set by the power supply voltage and current and travel speed along the weld joint. Figure 28-1-13 shows the apparatus needed.

A long arc, called a "spray arc" is used for high heat and heavy material. The "short arc" is used for thinner work.

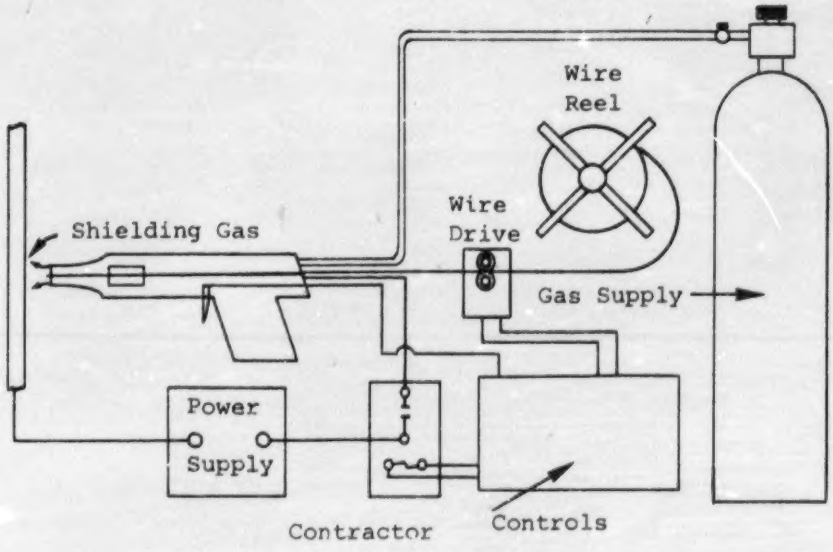



Figure 28-1-13 Schematic Diagram of Gas Metal Arc Welding Process

Uses of Metal Inert Gas Welding Process

The metal inert gas welding process can be used for all types of base metals. It is best suited for flat and horizontal welding positions and it is normally automated. Very high welding speeds are attainable. Disadvantages include accessibility requirements of the equipment, high installation costs, and likelihood of burn through with thin materials and fine porosity with any materials.

Submerged Arc Welding

Except for the absence of pressurized shielding gas, equipment for submerged arc welding is very similar to that used for metal inert gas welding. For example, spooled wire serves as both electrode and filler material and power supply and controls exist for synchronizing feed rate of the bare wire with the heating rate. The arc, however, is submerged in a granular flux that is preplaced on the work piece or fed through tubing surrounding the bare wire. The arc melts the base metal, bare wire and granular flux. The flux generates some shielding gases but provides a fairly thick, uniform molten slag that floats on the molten weld puddle and solidifies behind the travel of the arc. This slag protects the weld metal from adverse gases (oxygen, nitrogen). Figure 28-1-14 depicts the submerged arc welding apparatus.

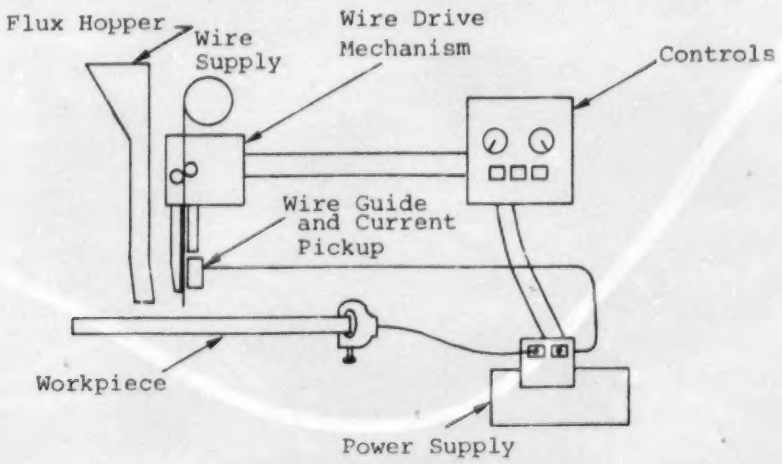



Figure 28-1-14 Schematic Diagram of Submerged Arc Welding Process

Uses of Submerged Arc Welding Processes

Submerged arc welding is employed primarily for welding steel alloys. It is normally automated although it is adaptable to a hand held gun. The flat welding position is most favorable although coffer dams may be used for holding the granular flux for horizontal positions. As with metal inert gas welding, very high welding speeds are attainable but accessibility of equipment and inability to weld thin base metal thickness give limitations. The fine porosity from the metal inert gas welding process does not occur in submerged arc welding.

## EXERCISES

The following exercises serve to reinforce the objectives presented in this module. Answer each question listed below. Refer back to the module only when necessary.

1. List the major duties of the QA/QC technician that are necessary during a welding inspection.
2. The configuration of the weld joint directly influences the strength of the joint, the ease of welding, and the probability of defect-free weldments. Identify the five basic types of joints used in welding.
3. List several considerations which must be made when choosing the type of welding joint.
4. The basic types of heat sources used in welding are fuel flame and electric arc. Briefly discuss the uses of each type.
5. The basic causes of distortion of the weld joint are the change in crystal size during welding and the temperature difference from the weld end faces to the

surrounding base material. Explain how distortion of the weld joint can be minimized.

6. Filler material is added to the joint to ensure that the weld is as thick as the base material. List the common types of filler rod.
7. What is the purpose of shielding during the welding process.
8. List the seven welding techniques that are common to all welding processes.
9. Each welding process has unique defects. However, there are nine defects that are common to practically all welding processes. List these nine types of defects.
10. Welding affects the mechanical properties of the weldment. Whenever there is an adverse effect on mechanical properties, heat treatment countermeasures are specified in the welding procedures. Briefly discuss the types of heat treatment countermeasures employed to minimize the effects on the mechanical properties of the weldment.
11. Perform the Procedures outlines in this module. These include:
    a. Gaining familiarity with welding reports
    b. Inspecting weld qualification test specimens
    c. Touring a welding shop and preparing a report.

## MATERIALS

The following materials are required to support this module.

1. One or more issues of NUREG-0040, "Licensee, Contractor, and Vendor Inspection Status Report of Inspection and Inforcement (Optional; see Procedure #1).
2. Selected case studies of defective welds (optional; see Procedure #2).
3. Samples of welded joints, with and without defects.

# PROCEDURES

1. Read NRC report NUREG-0040 (Quarterly Publication) Licensee Contractor and Vendor Inspection Status Report of Inspection and Enforcement on defective welds and prepare a brief written or oral summary of the report.
2. Read case studies of the consequences of defective welds. Prepare a brief written or oral report of one or more case studies.
3. Inspect weld qualification test specimens. Given the appearance of the specimen(s), identify the welding technique(s) used. Conduct a visual examination to locate defects.
4. Go on a guided tour of a welding shop. As you go through the welding shop, observe as many of the following items as possible. Answer the questions or fill in the information that is requested. Discuss the information in class.
   a. What type of welding process(es) is used? ____
   _____
   _____
   b. What apparatus is used? _____
   _____
   _____
   c. What heat source is used? _____
   _____
   d. Describe the method of shielding. _____
   _____
   _____
   e. Describe the filler material. _____
   _____
   _____
   f. Describe the welding technique. _____
   _____

g. What, if any, visible defects are present in the finished weld? _____

_____

_____

## DATA TABLE

None.

## REFERENCE MATERIALS

ASME, Boiler and Pressure Vessel Code, Sections III and IX, 1979, The American Society of Mechanical Engineers

AWS, Structural Welding Code, AWS D1.1 and Reinforcing Steel Welding Code, D12.1, American Welding Society

ARCOS, Arcos Pamphlet GC47620, Welding Products, Arcos Corporation, 1500 South 50th. Street, Philadelphia, Pennsylvania.

# TEST

MATCHING: Match each term given in the left-hand column with the correct definition given in the right-hand column. Place the letters of the definitions next to the terms they match.

1. ____ heat affected zone
2. ____ weld metal
3. ____ fusion zone
4. ____ toe
5. ____ reinforcement
6. ____ included angle
7. ____ weld end face
8. ____ root gap

a. The base metal whose chemistry and physical properties are unaffected by the welding process.

b. The distance between the surfaces to be welded as measured at the bottom of the weld joint.

c. The volume of base metal and filler material in the vicinity of the weld end faces which melts and resolidifies during the welding process.

d. The interface of either side of the weld metal with the base metal along the logitudinal surfaces of the weld joint.

e. Volume of base metal that does not melt but whose physical properties are altered by welding heat.

f. Surface area of the surfaces to be welded.
g. Controlled movement of the flame along the weld joint to permit melting of new areas.
h. Angle formed by perpendicular centerline of the weld joint and weld end face.
i. Volume of metal whose chemistry and physical properties are the same as the mixture of added filler and base metal.
j. Weld metal thickness in excess of nominal base material thickness specified for the weld joint.

Multiple Choice: Circle the letter of the response that best completes statements 9 through 16.

9. The lap joint is used only in areas where:
   a. the highest stress will be applied
   b. the stresses throughout the joint can be equalized
   c. there is low stress or moderate stress in the direction parallel to the plate surfaces
   d. the weave bead technique can be used

10. The heat source used in welding must be able to:
    a. input heat rapidly in order to melt weld end faces only
    b. bring the metal mass to the melting point of the base metals
    c. melt weld end faces and base metals
    d. create new crystals that are different in size from the base metal crystals

11. When there is a large temperature difference (gradient) between the weld end faces and the surrounding base metal:
    a. complete fusion takes place easily
    b. there is no need to physically restrain the parts to be welded
    c. weld joint distortion is minimized because thermal stresses are reduced
    d. weld joint distortion due to internal stresses is likely to occur

12. When the weld metal is formed solely by melting the weld end faces:
    a. the weld is thinner than the base metal
    b. the weld and the base metal are of the same thickness
    c. the welded places are thicker than the base metal
    d. only a small amount of heat input is needed to make a successful weld

13. The purpose of shielding in welding is:
    a. to prevent the welder from being in direct contact with the heat source
    b. to encourage the formation of oxides and nitrides in the weld
    c. to displace hydrogen, nitrogen and oxygen from the vicinity of the weld joint with a substance not harmful to the weld
    d. to conduct oxygen to areas of the weld where it can have the most beneficial effect on the heat source

14. In the forehand and backhand welding technique it is possible to shape the molten weld puddle because:
    a. fewer passes of the heat source are used
    b. the flame or electric arc exerts a force which pushes the molten puddle in the direction of the force
    c. the fusion zone constantly changes from weld end face to weld bead
    d. very low heating rates can be used

15. There is a relatively high probability of incomplete fusion in the weave bead technique because:
    a. so few weld beads are used
    b. gravity attracts the molten weld puddle
    c. pure oxygen is likely to combine with nitrogen to form harmful nitride
    d. the weld puddle is pushed in several directions and the fusion zone alternates between weld end face and weld bead

16. The positional welding techniques that have the highest degree of difficulty for making a sound weld are:
    a. interpass cleaning technique and vertical progression
    b. flat and vertical
    c. overhead and vertical
    d. reverse side and vertical progression

Completion:

Fill in the name of the defect which is described by each phrase for questions 17 through 24.

17. A cracking in the heat affected zone caused by hydrogen and excessive heating and cooling rates. _____

_____

18. Excessive reinforcement at the root of the weld. ___

_____

19. Failure to melt together the filler metal and the base metal. _____

20. An intermittent or continuous depression along the toe or root of the weld left unfilled by weld metal.

_____

21. A convex or concave irregularity on the root surface or adjacent base metal caused by the falling away of weld metal. _____

22. A depression in the root surface of the joint that can be caused by gravity. _____

23. Cavities in the weld metal caused by trapped gases. _____

24. Entrapped foreign material in the weld metal. _____

Fill In:

Fill in the name of the welding process that best meets the description given in questions 25 through 34.

25. In addition to an electrical power supply and pressurized shielding gas, this process requires controls to feed bare wire into the arc at a sufficient rate. _____

26. This process can be used in any position because it offers good control of size and flow of the molten weld puddle. _____

27. In this process, the arc is maintained between the bare wire and the work piece and the bare wire is constantly melting. _____

28. In this process, the arc is in a granular flux that is preplaced on the work piece or fed through tubing that surrounds the bare wire. _____

29. In this welding process, which does not use pressurized shielding gas, spooled wire serves as both the electrode and the filler material and the power supply and control synchronize the feed rate of the bare wire and the heat rate. _____

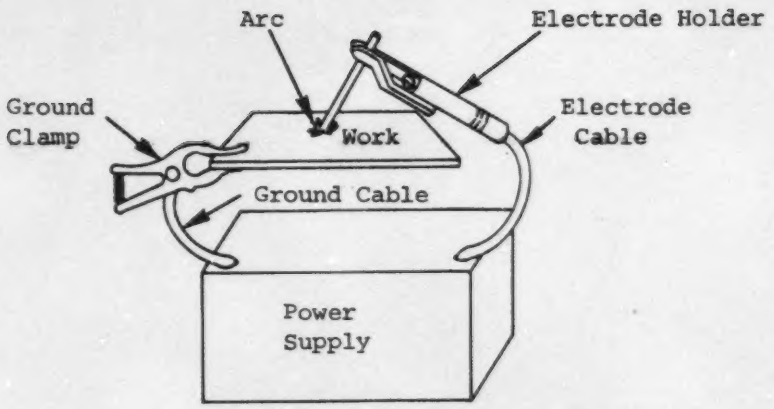
30. In this welding process, the electrode's coating melts to provide the shielding and the core wire melts to provide filler material._____

31. This process is often used for root pass welding because precise heating rates are obtainable and because no slag is present. _____

32. This process permits only a slow to moderate welding speed and cannot be used to weld diameters smaller than the cup surrounding the electrode. _____

33. This is a fuel flame welding process in which the welder manipulates the inner core of the flame to control weld puddle size and flow and in which the outer envelope of the flame provides shielding. _____
_____

34. This process uses the apparatus shown on next page.
_____


Arc
Electrode Holder
Ground
Clamp
Work
Electrode
Cable
Ground Cable
Power
Supply